A-RFS
CASE HISTORY

Detecting Damage to Bearing Surfaces In A F110-GE-100 Gas Turbine Engine

BACKGROUND:

Atomic emission spectroscopy (AES) using a rotating disc electrode (RDE) has been a successful technique applied to condition monitoring (oil analysis) programs for decades. However, in recent years the AES technique has become less effective as an early detection diagnostic technique. The reasons for the reduction in the effectiveness of the AES technique are primarily due to fine filtration and the morphology of particles that are generated at the onset of failures in M50 alloy rolling element bearings. Rotrode Filter Spectroscopy (RFS) is an analytical technique that has been developed to enhance the sensitivity of the AES-RDE technique in order to overcome these limitations.

Automated rotrode filter spectroscopy (A-RFS) is a sample preparation device designed for the AES that concentrates large and small wear metal debris in a graphite filter electrode. When the graphite filter electrode is analyzed using AES, sensitivity is increased by a factor of 80-100 and particle size detection is improved by a factor of 10. For example, the limit of detection of iron for conventional AES is 600 parts per billion. This limit of detection is reduced to 6 parts per billion by applying the A-RFS sample preparation technique. When the sample is prepared by the A-RFS device the particle size detection capability of AES is extended from 8-10 micrometers to greater than 70 micrometers.

By concentrating 5 ml of oil sample (50 times what is analyzed by conventional AES analysis), all particle debris (metallic and non-metallic) becomes trapped within the outer circumference of the graphite filter electrode. This process eliminates the major limitations (gravity, oil, resonance time) of conventional AES analysis. Efficient vaporization of all particles (large and small) is achieved using the total energy produced by the excitation source to reach vaporization temperatures in excess of 5,600 degrees Celsius. This is particularly important when alloy identification (such as M50) is necessary and damaging contaminants, such as silicon containing particles are present. When applied to aviation gas turbine engine oil analysis, the A-RFS can enhance the effectiveness of AES to detect the harmful effects of lubricant contamination and the subsequent bearing damage. The A-RFS is shown in operation next to the arc emission spectrometer in Figure 1.

Figure 1.   A-RFS Device in Operation

TEST SITE:

The United States Air Force (USAF) has successfully used the AES technique as their primary condition monitoring technique for several decades. To fully understand the capability of rotrode filter spectroscopy, the USAF initiated a pilot program to apply A-RFS analysis to the F110-GE-100 engines at selected test sites. This case history will provide one example of how the A-RFS technique enhanced the AES capability to identify a failure and its root cause, siliceous contamination. For security reasons, the name and location of the Air Force Base and the engine serial number have been withheld.

TEST TECHNIQUES:

A-RFS pilot program locations have been chosen by the USAF based on the availability of aircraft with F110-GE-100 engines, scanning electron microscope/energy dispersive x-ray (SEM/EDX) instrumentation, and fully staffed non-destructive inspection (NDI) laboratories with AES capabilities. These sites have enhanced AES instruments that include the element vanadium (V) and the A-RFS sample preparation device. The element vanadium is essential in the detection of M50 and M50 NiL alloys.

The SEM/EDX is an instrument that performs microscopic x-ray analysis of ferrous wear metal debris that is collected by a magnetic chip detector (MCD) installed in the oil return line of the gas turbine engine. Upon completion of each flight mission, the MCD is removed and replaced. The MCD from the completed mission is sent to the NDI laboratory where the microscopic ferrous metallic debris is transferred onto a carbon patch. The carbon patch is placed into the scanning electron microscope for analysis. If the debris is of sufficient size and quantity, a second more thorough scan analysis is performed followed by a maintenance recommendation. For comparison purposes, this case history will include all SEM/EDX data that was available.

AES ANALYSIS:

This section of the case history contains the conventional arc emission spectroscopic (AES) analysis of the subject engine. The serial number of this engine has been removed from this record for security reasons.

TEC	DATE	T-HRS	OIL-HRS	FE	AG	AL	CR	CU	MG	V	NI	PB	SI	SN	TI	B	MO	ZN
FHAA	2006156	6323	512	0.1	0	0	0	0.1	0	0.4	0	0	0	2.8	0.5	0	0	0
FHAA	2006159	6325	514	0.1	0	0	0.1	0.2	0	0	0.1	0	0	4	0.6	0	0	0
FHAA	2006159	6327	516	0.2	0	0	0	0.2	0	0	0	0	0	3.4	0.6	0	0	0
FHAA	2006160	6329	518	0.1	0	0	0	0.2	0	0	0	0	0	3.7	0.5	0	0	0
FHAA	2006162	6331	520	0.1	0	0	0.1	0.2	0	0	0	0	0	3.4	0.5	0	0	0
FHAA	2006162	6332	521	0	0	0	0.1	0.2	0	0	0.1	0	0.1	4.1	0.5	0	0	0
FHAA	2006162	6334	523	0	0	0	0	0.2	0	0	0	0	0	2.4	0.4	0.1	0	0
FHAA	2006165	6336	525	0	0	0	0.1	0.1	0	0	0	0	0	2.8	0.4	0	0	0
FHAA	2006166	6338	527	0	0	0	0.1	0.1	0	0	0.1	0	0	3.6	0.3	0.1	0	0
FHAA	2006172	6339	528	0	0	0	0	0.2	0	0	0.2	0	0	3.2	0.5	0.1	0	0
FHAA	2006172	6340	529	0	0	0	0	0.2	0	0	0.1	0	0	3.8	0.5	0	0	0
FHAA	2006173	6341	530	0	0	0	0.2	0.2	0	0	0.3	0	0	3.8	0.4	0.1	0	0
FHAA	2006176	6348	537	0	0	0	0	0.2	0	0	0.1	0	0	2.7	0.3	0	0.1	0
FHAA	2006176	6350	539	0.1	0	0	0.1	0.2	0	0	0.1	0	0	4.3	0.5	0	0	0
FHAA	2006177	6351	540	0	0	0	0.3	0.2	0	0	0.1	0	0	4.7	0.4	0	0	0
FHAA	2006177	6352	541	0	0	0	0	0.2	0	0	0.1	0	0	3.7	0.5	0	0	0
FHAA	2006178	6353	542	0.1	0	0	0.2	0.2	0.2	0	0.2	0	0	4.9	0.4	0.1	0	0
FHAA	2006178	6355	544	0	0	0	0	0.2	0	0	0	0	0	4.3	0.6	0	0	0
FHAA	2006179	6356	545	0.1	0	0	0.1	0.2	0	0	0.2	0	0	5	0.5	0	0	0
FHAA	2006179	6357	546	0.3	0	0	0.1	0.2	0	0	0.3	0	0	4.5	0.6	0	0	0
FHAA	2006180	6358	547	0.1	0	0	0.2	0.2	0	0	0.2	0	0	5.3	0.4	0	0	0
FHAA	2006180	6359	548	0.1	0	0	0.1	0.2	0	0	0.1	0	0	3.3	0.5	0	0	0
FHAA	2006185	6360	549	0.1	0	0	0	0.2	0	0	0.1	0	0	5	0.5	0.1	0	0
FHAA	2006187	6361	550	0.1	0	0	0.2	0.2	0	0	0.1	0	0	5.2	0.7	0	0	0.6
FHAA	2006187	6362	551	0.1	0	0	0	0.2	0.1	0	0.1	0	0	5.2	0.3	0.1	0	0.1
FHAA	2006187	6363	552	0.1	0	0	0.1	0.2	0	0	0.1	0	0	5.4	0.5	0.1	0	0
FHAA	2006188	6364	553	0	0	0	0.1	0.2	0	0	0.2	0	0	4.3	0.5	0.1	0.1	0
FHAA	2006188	6365	554	0.2	0	0	0	0.2	0	0	0.2	0	0	4.7	0.3	0	0	0
FHAA	2006191	6367	556	0.2	0	0	0	0.1	0	0	0.1	0	0	4.4	0.6	0.1	0	0
FHAA	2006192	6368	557	0	0	0	0	0.1	0	0	0.1	0	0	4	0.7	0.1	0	0
FHAA	2006192	6369	558	0	0	0	0	0.2	0	0	0.1	0	0	4.3	0.5	0	0	0
FHAA	2006194	6370	559	0.7	0	0	0	0.2	0	0	0	0	0	3.8	0.4	0	0	0
FHAA	2006194	6372	561	0.6	0	0	0	0.2	0	0	0.2	0	0	3.4	0.5	0	0	0
FHAA	2006195	6374	563	0.8	0	0	0	0.2	0	0	0.1	0	0	4.6	0.6	0	0	0
FHAA	2006195	6376	565	0.5	0	0	0.1	0.2	0	0	0	0	0	3.9	0.3	0	0	0
FHAA	2006197	6377	566	0.5	0	0	0	0.2	0	0	0.1	0	0	3.9	0.3	0	0	0
FHAA	2006199	6378	567	0.4	0	0	0	0.2	0	0	0	0	0	3.8	0.4	0	0	0
FHAA	2006200	6379	568	0.6	0	0	0	0.2	0	0	0	0	0	4	0.4	0	0	0
FHAA	2006201	6381	570	0.6	0	0	0.1	0.2	0	0	0.2	0.4	0	3.8	0.6	0	0.2	0
FHAA	2006202	6403	592	0	0	0	0	0.1	0	0	0	0	0	4.1	0.4	0	0	0
FHAA	2006218	6405	594	0.4	0	0	0	0.2	0	0	0.2	0	0	3.4	0.6	0	0	0
FHAA	2006218	6407	596	0.6	0	0	0	0.2	0	0	0.1	0	0	4.4	0.6	0	0	0
FHAA	2006220	6408	597	0.6	0	0	0.1	0.2	0	0	0.2	0	0	4.5	0.6	0	0	0
FHAA	2006221	6410	599	0.7	0	0	0.1	0.2	0	0	0	0	0	5	0.3	0	0	0
FHAA	2006221	6411	600	0.6	0	0	0	0.2	0	0	0.1	0	0	4.2	0.3	0	0	0
FHAA	2006223	6413	602	1	0	0	0	0.1	0	0	0.1	0	0	4.5	0.6	0	0	0
FHAA	2006223	6415	604	0.9	0	0	0	0.2	0.4	0	0	0	0	4.2	0.6	0	0	0
FHAA	2006224	6417	606	0.6	0	0	0	0.2	0	0	0	0	0	2.7	0.3	0	0	0
FHAA	2006227	6419	608	1	0	0	0	0.2	0	0	0.1	0	0	4.4	0.5	0	0	0
FHAA	2006229	6421	610	0.7	0	0	0.1	0.2	0	0	0.1	0	0	3.5	0.5	0	0	0
FHAA	2006229	6423	612	0.3	0	0	0.1	0.2	0.1	0	0.1	0	0	4.5	0.4	0	0	0
FHAA	2006230	6425	614	0.3	0	0	0.1	0.2	0	0	0	0	0	4	0.1	0	0	0
FHAA	2006293	6425	614	0.5	0	0	0	0.1	0	0	0	0	0	3	0.5	0	0	0
FHAA	2006293	6426	615	0.5	0	0	0.1	0.1	0	0	0	0	0	3.5	0.3	0	0	0
FHAA	2006294	6427	616	0.5	0	0	0.2	0.1	0	0	0.1	0	0	2.9	0.6	0	0	0
FHAA	2006300	6428	1	0.4	0	0	0.1	0.1	0	0	0	0	0	2.7	0.3	0	0	0
FHAA	2006300	6429	2	0.5	0	0	0	0.1	0	0	0	0	0	3.6	0.4	0	0	0
FHAA	2007031	6430	3	1.1	0	0	0	0.2	0	0	0	0	0	3.3	0.1	0	0	0
FHAA	2007031	6431	4	0.9	0	0	0.1	0.2	0.1	0	0	0	0	4.9	0.6	0	0	0
FHAA	2007033	6432	5	0.2	0	0	0	0.1	0	0	0	0	0	2.7	0.3	0	0	0
FHAA	2007033	6433	6	0.3	0	0	0	0.1	0	0	0	0	0	3.2	0.4	0	0	0
FHAA	2007036	6434	6	0.4	0	0	0	0.1	0	0	0	0	0	2.8	0.5	0	0	0
FHAA	2007036	6435	8	0.5	0	0	0	0.1	0	0	0	0	0	2.8	0.5	0	0	0
FHAA	2007058	6436	9	0.3	0	0	0.1	0.1	0	0	0	0	0	4.3	0.4	0	0	0
FHAA	2007060	6437	10	0.3	0	0	0.1	0.1	0	0	0	0	0	3.5	0.2	0	0	0
FHAA	2007061	6439	12	0	0	0	0	0	0.2	0	0	0	0	2.8	0	0	0	0
FHAA	2007062	6441	14	0.1	0	0	0.1	0	0	0	0	0	0	2.9	0.2	0	0	0
FHAA	2007063	6442	15	0.3	0	0	0	0.1	0	0	0.1	0	0	3.5	0.2	0	0	0
FHAA	2007065	6443	16	0.4	0	0	0.1	0.1	0	0	0	0	0	3.9	0.3	0	0	0

Table 1. AES Analysis of F110-GE-100 Engine

A quick review of this engine analysis record provides no evidence of an abnormal mechanical condition or contaminant presence, particularly for the elements iron and silicon whose analytical results are basically zero. In accordance with the technical order, this engine is operating within normal operating parameters

A-RFS ANALYSIS:

This section of the case history contains the RFS analysis of the subject engine. RFS analysis is performed by the same atomic emission spectrometer after preparation of the filter electrode by the A-RFS device. The difference in the concentration between the AES measurement and RFS measurement is due to three factors. RFS analyzes a larger sample volume. RFS eliminates the negative effect gravity has on transporting large particles to the excitation source and it produces higher excitation temperatures for greater vaporization efficiency.

TEC	DATE	T-HRS	OIL-HRS	FE	AG	AL	CR	CU	MG	V	NI	PB	SI	SN	TI	B	MO	ZN
FHAA	2006124	6260	449	11.8	0.2	1	0.9	2.3	2.1	3.4	1.3	0.1	8.3	1.5	1.9	2.2	0.5	107
FHAA	2006125	6260	449	3.4	0.1	0.1	0.1	0.7	0.9	1.7	0.1	0.1	4.4	0.1	0.6	0.4	0.1	18.4
FHAA	2006126	6265	454	4.3	0.3	0.7	0.5	1.6	0.6	1.1	0.7	1	3.6	2.9	1.1	1.1	0.8	51.9
FHAA	2006130	6270	459	30.6	0.1	0.1	1.8	6.4	2.4	3.4	4.1	0.1	12.0	0.1	1.2	0.8	0.1	34.8
FHAA	2006131	6306	495	13.4	0.1	0.1	0.6	3.4	2.9	5.6	0.1	0.1	8.8	0.1	0.6	0.8	0.1	57.6
FHAA	2006132	6307	496	5.3	0.1	0.1	0.1	2.7	1.5	3.1	0.1	0.1	5.7	0.1	0.7	0.3	0.1	55.4
FHAA	2006132	6308	497	13.5	0.1	0.4	0.4	5.2	4	8.1	1.5	0.1	15.4	0.1	2.8	0.9	0.1	77.3
FHAA	2006134	6310	499	8.3	0.1	0.1	0.1	3.5	2.7	7.2	0.1	0.1	7.9	0.1	0.9	1.3	0.1	52.2
FHAA	2006134	6311	500	32.8	0.1	0.4	3.4	6.1	2.7	3.4	5.6	0.1	11.1	0.1	2.7	0.7	0.1	104
FHAA	2006135	6312	501	35.8	0.1	0.1	3	3.1	3	31	6.1	0.1	6.0	0.1	0.1	9.2	0.1	53.6
FHAA	2006143	6313	502	12.3	0.3	2.5	0.3	4.6	4	7.3	0.8	0.1	13.4	3.8	1.7	2.5	0.3	59.7
FHAA	2006150	6315	504	25.2	0.4	5.2	0.8	8.1	5.6	17.2	1.4	0.1	27.3	5.4	4.6	3	0.1	77.7
FHAA	2006151	6317	506	34.2	0.4	6.7	0.9	10.1	9.4	14.3	2.4	1	48.7	5.8	3.8	3.4	0.9	93.9
FHAA	2006151	6318	507	18.2	0.4	2.3	0.6	3.6	2.8	4.3	1.5	0.1	11.3	4.3	2.4	1	0.8	62.8
FHAA	2006156	6323	512	13.2	0.4	2.1	0.2	2.2	2.8	2.7	0.3	0.1	15.3	6	1.3	1.1	0.3	39.9
FHAA	2006159	6325	514	41.2	0.8	12.6	1.8	10.6	12.5	19.2	2.7	0.4	64.7	9.8	8.4	3.1	1	31
FHAA	2006159	6327	516	127.0	0.5	9.6	6.6	10.5	12.8	14.3	9.6	0.1	72.0	4.1	9.1	2.5	1	78.2
FHAA	2006160	6329	518	57.5	1.1	13.4	1.3	18.9	17.8	23.8	2.8	0.1	100.0	5.1	11.7	3.3	1.1	60.7
FHAA	2006162	6332	521	73.0	0.6	12.2	0.3	11.2	12.2	12.3	1.8	0.3	85.1	5.7	7.4	2.4	1.2	23.4
FHAA	2006162	6334	523	49.4	0.8	8.7	0.6	8.6	10	17.3	1.5	0.1	59.3	2.1	5.4	2.9	0.6	15.8
FHAA	2006165	6336	525	8.7	0.3	1	0.1	2.7	1.4	3.9	0.3	0.1	4.9	0.8	1	0.4	0.3	8.8
FHAA	2006178	6352	541	29.9	0.4	2.8	0.7	4.4	3.2	7.1	1.3	0.1	19.2	0.1	1.9	0.6	0.4	9
FHAA	2006179	6353	542	31.6	0.4	5.3	0.4	5.3	5.3	12.1	1.2	0.4	29.5	2.8	3.5	2.1	0.8	10.4
FHAA	2006180	6356	545	33.0	0.3	5.8	0.7	8.1	6.2	10.9	2.1	0.1	35.9	2.7	3.4	1.1	0.1	13.5
FHAA	2006180	6357	546	31.8	0.1	5.5	0.2	7.7	7.5	20.7	0.4	0.1	34.9	0.5	3.7	0.5	0.1	11.2
FHAA	2006181	6358	547	86.2	0.4	13.5	1.8	17.6	14.8	45.1	3.3	0.1	69.4	4.7	8.2	7.9	0.1	19.8
FHAA	2006181	6359	548	64.6	0.5	17.7	1	33.6	20.9	54.3	2.8	0.1	82.3	7.2	9.1	3.1	0.1	34.1
FHAA	2006187	6361	550	20.0	0.2	4	0.1	4.3	5.1	7.2	0.8	0.4	26.3	2.1	3.1	1	1	9.9
FHAA	2006218	6411	600	8.3	0.5	2.9	0.1	2.5	2.1	3.2	0.2	0.5	8.3	5.9	1.8	0.7	1.4	11.6
FHAA	2006304	6425	614	0.1	0.2	0.1	0.1	0.3	0	0.1	0.1	0.1	0.1	0.1	0.6	0.2	0.1	0.1
FHAA	2006304	6426	2	7.6	0.7	0.5	0.1	0.3	0.5	0.1	0.1	0.1	0.8	0.6	0.8	0.1	0.1	1
FHAA	2006304	6426	2	3.2	0.5	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.4	0.3	0.1	0.1
FHAA	2006304	6427	3	5.9	0.6	0.6	0.3	0.6	0.2	0.3	0.3	0.1	0.2	0.4	0.8	0.1	0.8	0.1
FHAA	2006304	6427	3	17.4	1.1	2.1	0.9	1.9	2.2	0.5	1.4	0.7	7.3	2	1.6	0.9	1.8	14
FHAA	2006304	6429	5	2.0	0.6	0.5	0.1	0.1	0.1	0.3	0.2	0.7	0.1	0.1	0.6	0.4	0.7	0.1
FHAA	2007031	6431	7	33.4	1.4	0.4	1.4	0.6	0.7	0.1	0.5	0.2	1.0	0.1	0.7	0.1	2.4	17.3
FHAA	2007055	6436	12	26.9	1.1	0.5	0.8	1.6	1.9	0.4	1.1	0.1	7.8	0.1	1.2	0.8	0.1	15.5
FHAA	2007060	6437	13	13.1	0.6	0.8	0.5	1.5	2.1	0.5	1.2	0.1	10.2	0.1	1	0.1	0.1	11.7
FHAA	2007062	6441	17	2.1	0.2	0.1	0.2	0.1	0.8	0.1	0.1	0.1	0.1	0.1	1.6	0.1	0.1	6
FHAA	2007063	6442	18	2.7	0.1	0.1	0.1	0.4	1	0.1	0.1	0.1	3.0	0.1	0.1	0.1	0.1	6.6
FHAA	2007065	6443	19	0.0	0.1	0.1	0.1	0.1	0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	1.6

Table 2. A-RFS Analysis of F110-GE-100 Engine

A quick review of this data, particularly for the elements iron and silicon, reveal abnormally high concentrations beginning at hour (T-HRS) 6325 and continuing through hour 6361. In addition, elements such as chromium, vanadium and nickel and molybdenum are also present and in tandem with iron and silicon. These elements are part of the M50 and M50 NiL chemistry.

GRAPH OF A-RFS IRON AND SILICON:

The following graph illustrates the change in trend starting at 6315 hours, after which abrasive silicon contamination apparently entered the lubricant system. There is noticeable correlation between the abrasive silicon contaminant and the iron concentration. Notations have been added to the A-RFS Iron and Silicon graph to aid in establishing correlation of the A-RFS and SEM/EDX analysis.

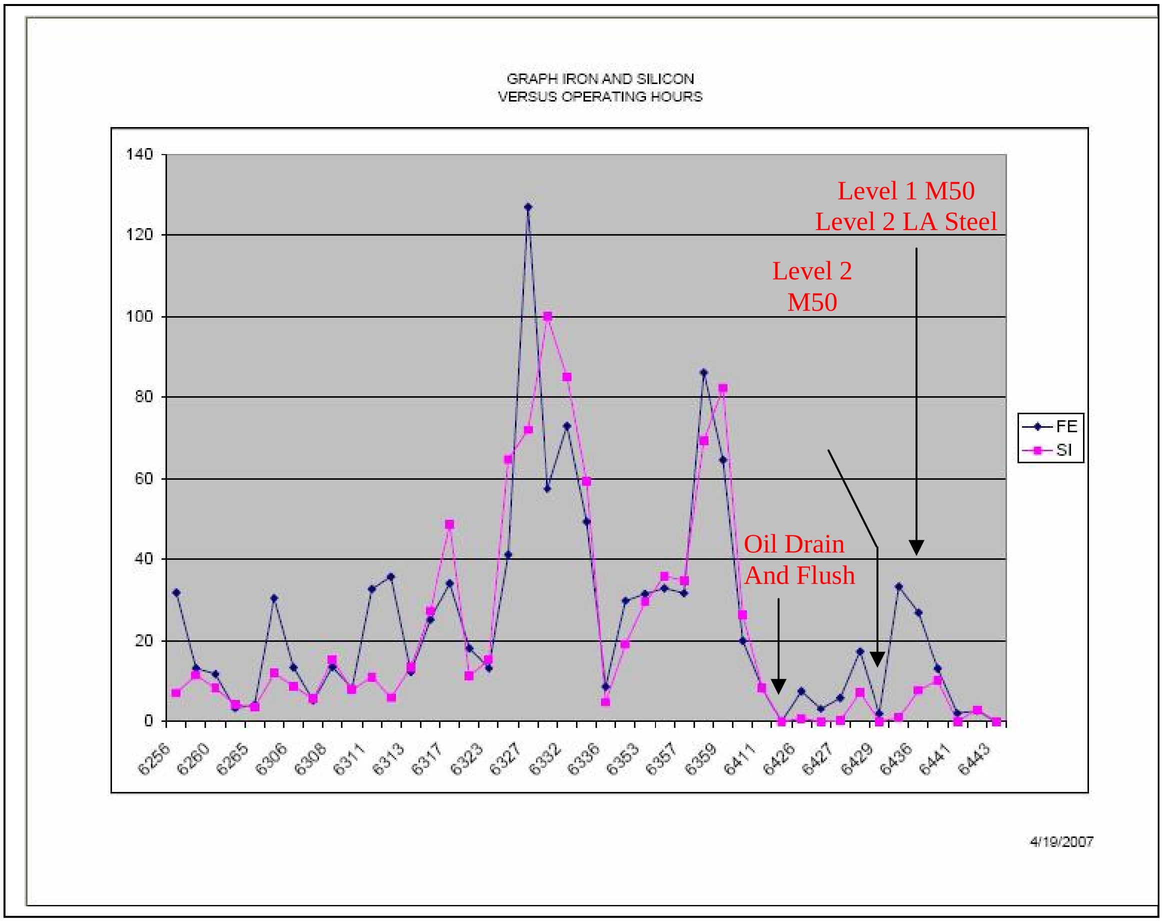

Figure 2. A-RFS History of Iron and Silicon from F110-GE-100 Engine

SEM/EDX ANALYSIS:

The SEM/EDX instrument used at the laboratory where this case history developed is a LEO JetSCAN®. The following information has been gathered from the "Diagnostic Report" and "Area Details for All Batches" report. Unfortunately, no SEM/EDX records prior to 6430 operating hours were available for inclusion in this case history report.

To simplify the SEM/EDX data, Table 3 has been generated to combine the data produced in the two reports mentioned above.

									ALLOYS						
OPERATING HOURS	M50	M50 NiL	9310/4340	17/4	410	347	A286	INCO 718	AG PLATE	LA STEEL	CR PLATE	NI PLATE	W CARBIDE	UNCLASSIFIED	TOTAL #	TOTAL AREA (sq thou)
6340	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6431	46	0	584	0	70	14	0	0	29	529	0	29	0	2310	72	3612
6432	3691	0	14	0	8	0	0	0	24	32	0	30	0	344	33	4143
6433	67	0	0	0	85	0	0	0	0	9	0	8	0	144	14	313
6434	31	55	0	0	33	39	0	0	10	0	0	63	0	66	17	297
6435	20	0	0	0	9	0	0	0	7	12	0	244	0	220	33	493
6436	0	31	0	0	0	0	0	0	0	0	0	71	0	274	12	376
6437	0	0	0	0	0	0	0	0	0	110	0	0	0	0	1	110
6439	288	48	0	0	7	19	0	0	15	2624	0	0	0	1690	65	4691
6441	0	0	104	0	0	0	0	0	0	28	0	0	0	137	5	269
6442	14	0	0	0	0	0	0	0	0	0	0	0	0	31	3	45
6443	8	0	0	0	0	0	0	0	0	0	0	0	0	0	1	8
6445	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6446	0	0	0	0	0	0	0	0	7	0	0	0	0	0	1	7
6447	0	0	0	0	0	0	0	0	0	11	0	6	0	0	2	17
6449	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6451	0	0	0	0	21	0	0	0	0	0	0	0	0	11	2	33
6453	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6455	14	0	0	0	0	0	0	0	0	0	0	0	0	0	1	14
6457	0	0	0	0	0	11	0	0	0	53	0	9	0	0	6	73
6459	14	0	0	0	0	0	0	0	11	0	0	0	0	8	3	33
6461	18	0	0	0	0	0	0	0	0	14	0	0	0	59	6	91
6463	35	0	15	0	0	0	0	0	0	9	0	0	0	17	5	76
6465	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6467	328	0	0	0	0	0	0	0	0	0	0	0	0	0	2	328
6468	0	0	0	0	96	0	0	0	0	236	0	0	0	246	9	578
6469	46	0	0	0	0	0	0	0	0	0	0	0	0	71	10	118
6471	0	0	0	0	0	0	0	0	0	79	0	0	0	23	6	102
6471	9	0	0	0	0	0	0	0	0	0	0	0	0	0	1	9
6471	0	0	17	0	45	0	0	0	0	0	0	0	0	0	2	61
	LEVEL 2									LEVEL 2				LEVEL 1		
	LEVEL 1															

Table 3. SEM/EDX History of F110-GE-100 Engine

Table 3 contains all alloys that have algorithms programmed into the SEM/EDX instrument for their detection and quantification. The values that appear under each alloy are the total area measured of each alloy in the sample. These values are reported in units of square thousandths. Alert levels have been established for each alloy type and each engine model. When these levels are reached or exceeded, a LEVEL alert is generated for maintenance action. Alert Level 1 has been color coded in yellow and Level 2 has been coded in orange for ease of identification.

POST MAINTENANCE ASSESSMENT:

This engine was taken out of service on or about 6411 operating hours. In addition to other components, the #4 (M50 NiL) and #5 (M50) bearings were replaced. Figure 3 below are photographs of the bearings removed during maintenance.

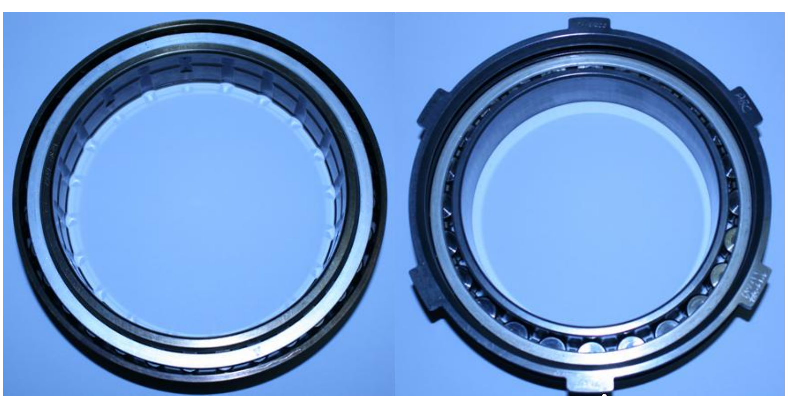

Figure 3. #4 and #5 Bearings Removed from F110-GE-100 Engine

Visual inspection of these bearings under magnification confirmed that surface damage caused by silicon particulate debris had occurred, as well as scoring of the rolling elements.

Figure 4 below contains photographs of the #4 bearing showing visible pitting caused by compression fractures due to abrasive silicon contamination in the lubricant. A-RFS analysis of the oil samples prior to removal provided clear evidence of the presence of this silicon debris as shown in Table 2. Elevated concentrations of nickel also identified that some damage was occurring to the #4 M50 NiL bearing.

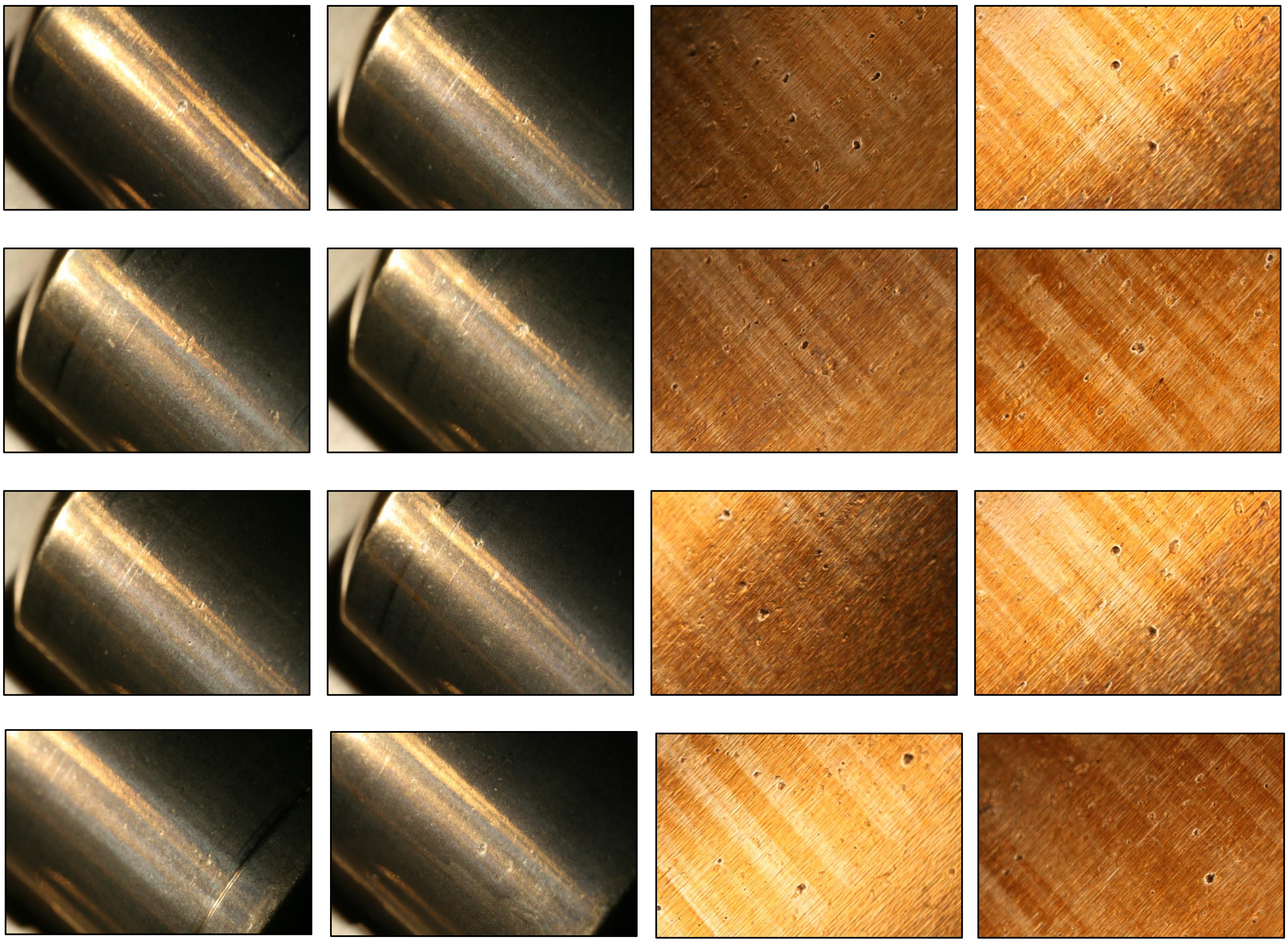

Figure 4. #4 Bearing Rollers and Outer Race from F110-GE-100 Engine

Figure 5 contains photographs of the #5 bearing exhibiting similar damage of the rolling elements inner race created by silicon compression fractures. The inner race of the #5 bearing did not exhibit the severe and frequent damage that was experienced with the #4 bearing. However, in most cases when the inner race of the #5 bearing is damaged, the characteristic of the damage appears as defined sliding scar versus centralized pitting.

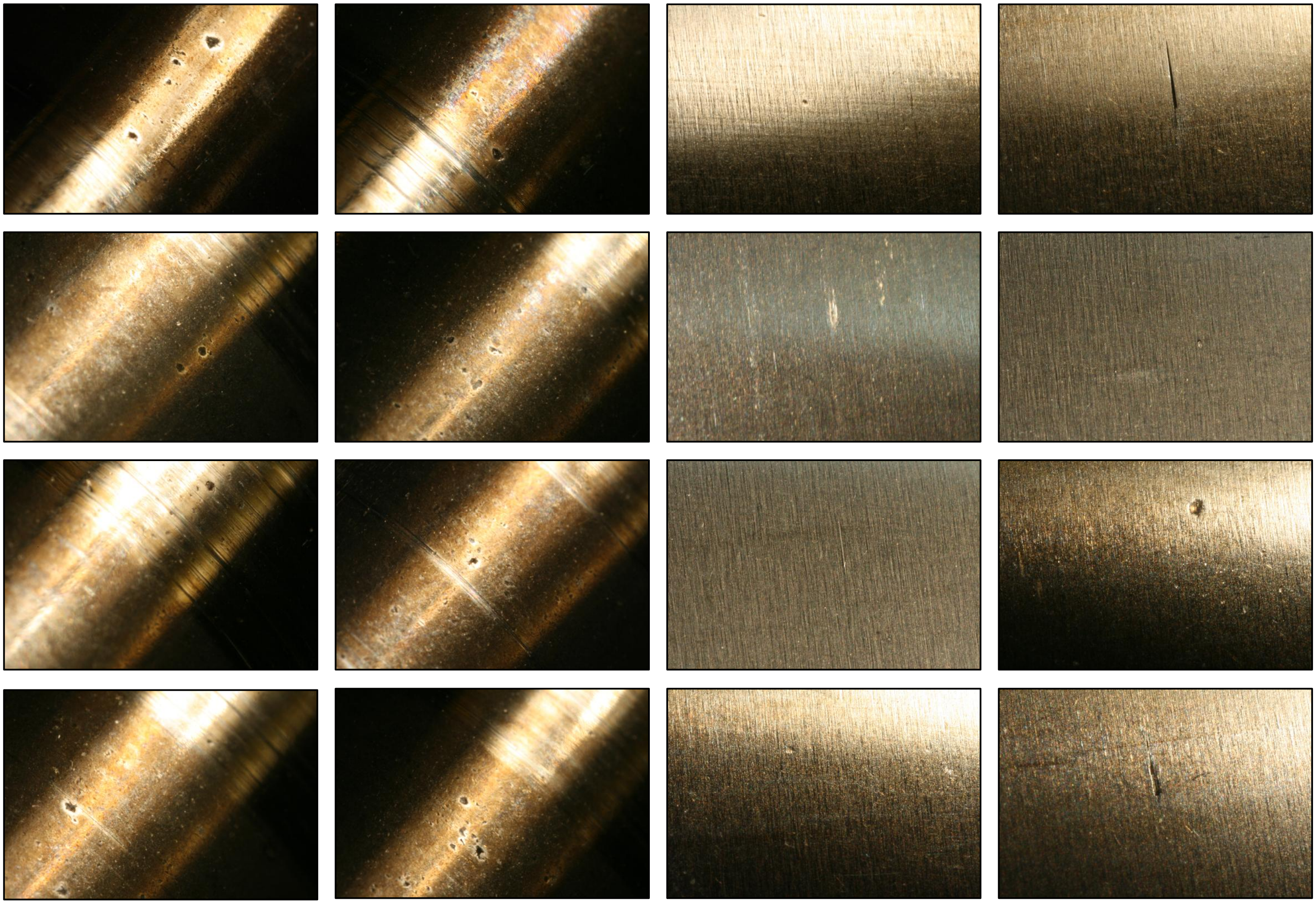

Figure 5. #5 Bearing Rollers and Inner Race from F110-GE-100 Engine

SUMMARY:

The USAF has successfully applied the Atomic Emission Spectrometer in their condition monitoring oil analysis program for several decades. Due to design changes in modern engines to improve filtration efficiency and the use of magnetic chip detectors (MCD's) plus advances in metallurgy have all contributed to a decline in the efficiency of the conventional AES technique.

To enhance the sensitivity and particle size detection capability of the atomic emission spectrometer, rotrode filter spectroscopy has been applied to aviation gas turbine engines. The USAF has pilot programs where A-RFS analysis is being performed simultaneously with AES analysis particularly at bases where F110-GE-100 engines are being operated. A-RFS analytical data is being generated on a routine basis and this data is compared to conventional AES and SEM/EDX analysis.

This case history is from one of the pilot bases where A-RFS oil analysis is performed. This base experienced an abnormal condition where A-RFS analysis detected elevated levels of silicon and wear metals consisting of bearing alloy chemistry. Conventional AES analysis of the same oil samples revealed no elevated presence of any of these elements. Complete SEM/EDX data throughout the full A-RFS case period was not available at the time of this report; however, the engine was removed from service presumably based on SEM/EDX recommendation.

Post maintenance engine records indicate that the gearbox, hydraulic pump, auxiliary fuel pump, lube and scavenge pump plus the #4 and #5 bearings were initially replaced. A thorough analysis of the #4 and #5 bearings confirmed extensive surface damage. After repair, the engine was run in a test cell where it continued to exceed SEM/EDX guidelines. The #1, #2, and #3 bearings were all replaced and returned back to the test cell. After several drains and flushing of the lubricant through the engine, it was returned to service.

CONCLUSION:

The A-RFS is an accessory for existing atomic emission spectrometers which aids in efficiently vaporizing all wear metals and contaminants in an oil sample from any gas turbine engine. Concentrating all debris contained in this sample is equivalent to analyzing 50 times the sample volume analyzed by conventional AES. The benefit gained by concentrating the debris is significant. It provides better statistical representation of the total lubricant contamination in the engine and it elevates fine filtered debris to a concentration that is detectable. Direct deposition of all debris in the pores of the graphite filter electrode results in more efficient sample introduction into the excitation source. Removal of the lubricant in the A-RFS process results in higher excitation energy for vaporization of larger particles and higher temperatures necessary to vaporize alloy elements such as vanadium and contamination in the form of silicon particles.

This case history provides evidence that the application of A-RFS in routine oil analysis of aviation gas turbine engines enhances the capability of conventional atomic emission spectrometers. The enhanced sensitivity and higher vaporization temperatures can result in early detection of component failure and component degradation due to unwanted lubricant contamination. The A-RFS sample preparation accessory to AES instruments is an improvement to any condition monitoring oil analysis program.